Pulsars and time scales

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Résumé

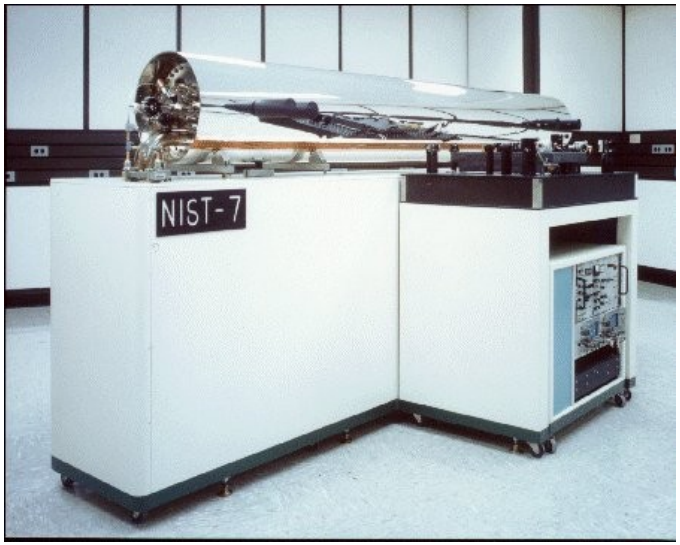
- EAL, TAI, TT(BIPM)
- Atomic time 10 years ago and now
- Pulsars and time
- Conclusions

Atomic clocks 1996

- First HP5071A appeared 1993

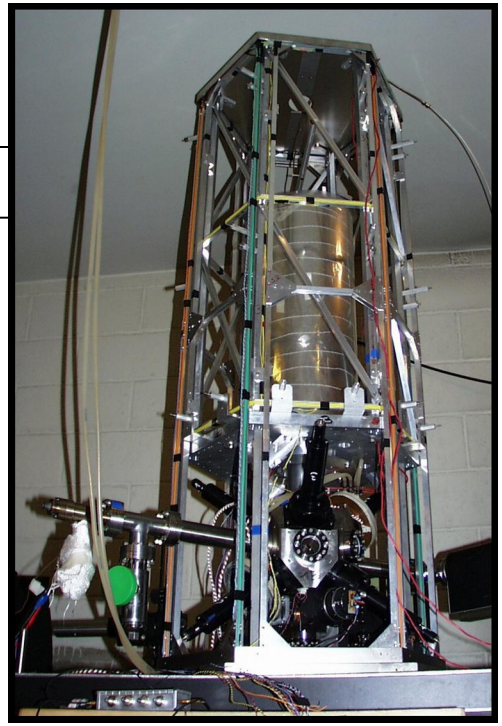
  A factor of 2-3 improvement in stability over previous clocks

- Laboratory Cs standards attain 1x10-14 accuracy (here NIST7, also PTB, etc...).
- And the first Cs foutain was operated in 1995.

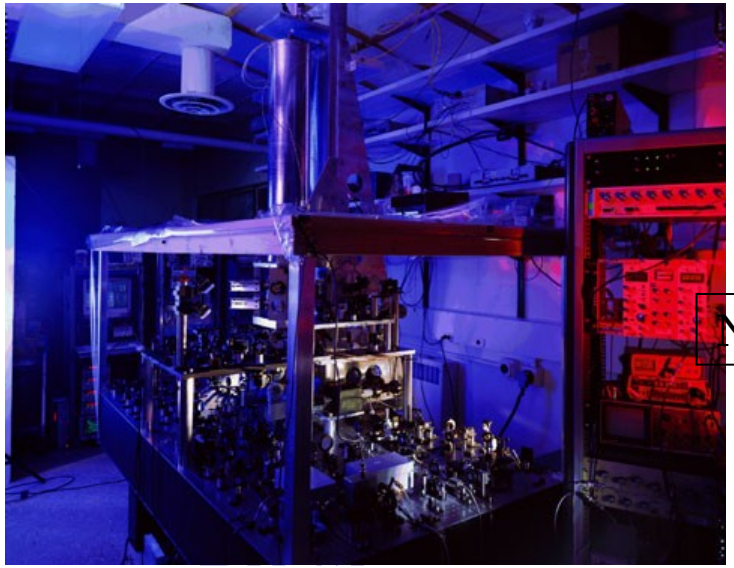


Atomic clocks now

- Industrial clocks not very much changed
- Cs fountains in
  - SYRTE: FO1 (in 1995-1997), FO2 and FOM (since 2002)
  - NIST: F1 (since end 1999)
  - PTB: CSF1 (since mid 2000)
  - IEN: CSF1 (since 2003)
  - NPL:CSF1 (since 2004)
  - NMIJ: JF1 (since 2005)
  - more coming



SYRTE Paris



NIST Boulder (USA)

EAL, TAI and TT(BIPMxx)

- TAI calculation (“real time”)
  - Each month, BIPM computes a free atomic scale EAL from more than 250 atomic clocks worldwide.
  - Each month, primary frequency standards (PFS) are used to estimate f(EAL).
  - The frequency of TAI is then steered

- TT(BIPMxx) calculation
  - Post-processed using all available PFS data, as of year 20xx.
  - f(EAL) is estimated each month using available PFS. Monthly estimates are smoothed and integrated to obtain TT(BIPMxx).
  - Last realization: TT(BIPM05), released in March 2006.

Atomic time 10 years ago, 1996

- G. Petit, P. Tavella, Pulsars and time scales, A&A308, 290, 1996
- G. Petit, Limits to the stability of pulsar time, Proc. PTTI, 1995

- Atomic time TAI
  - Stability from 150-170 clocks, HP5071A just appeared.
  - Accuracy and long-term (years) stability from 6-8 Cs tube PFS: Best value is 1×10^{-14}
  - 1-2 year instabilities $>1 \times 10^{-14}$ possible
- TT(BIPM)
  - Post-processed, mainly based on PFS
  - 1-2 year instabilities $<1 \times 10^{-14}$

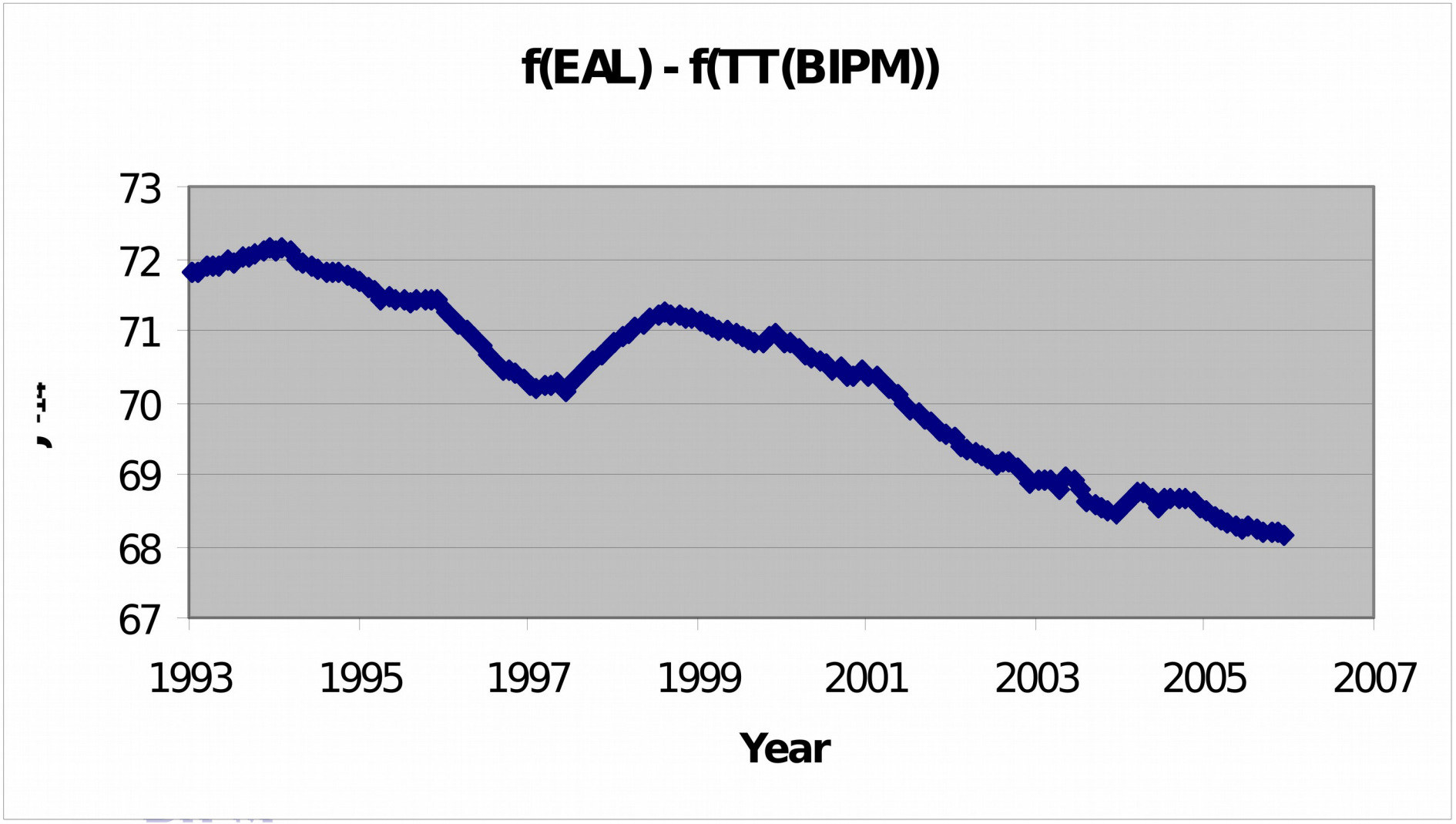
Atomic time now, 2006

- G. Petit, Long term stability and accuracy of TAI, Proc. EFTF, 2005
- (This meeting for recent publications on pulsars)

- Atomic time TAI
  - Stability from > 250 clocks, mostly HP5071A and H-masers
  - Accuracy and long-term (years) stability from 6-8 Cs fountain PFS: Best accuracy is 4×10^{-16}
  - 1-2 year instabilities $>2 \times 10^{-15}$ still possible, but not likely
- TT(BIPM)
  - Post-processed, mainly based on PFS
  - 1-2 year instabilities $<1 \times 10^{-15}$

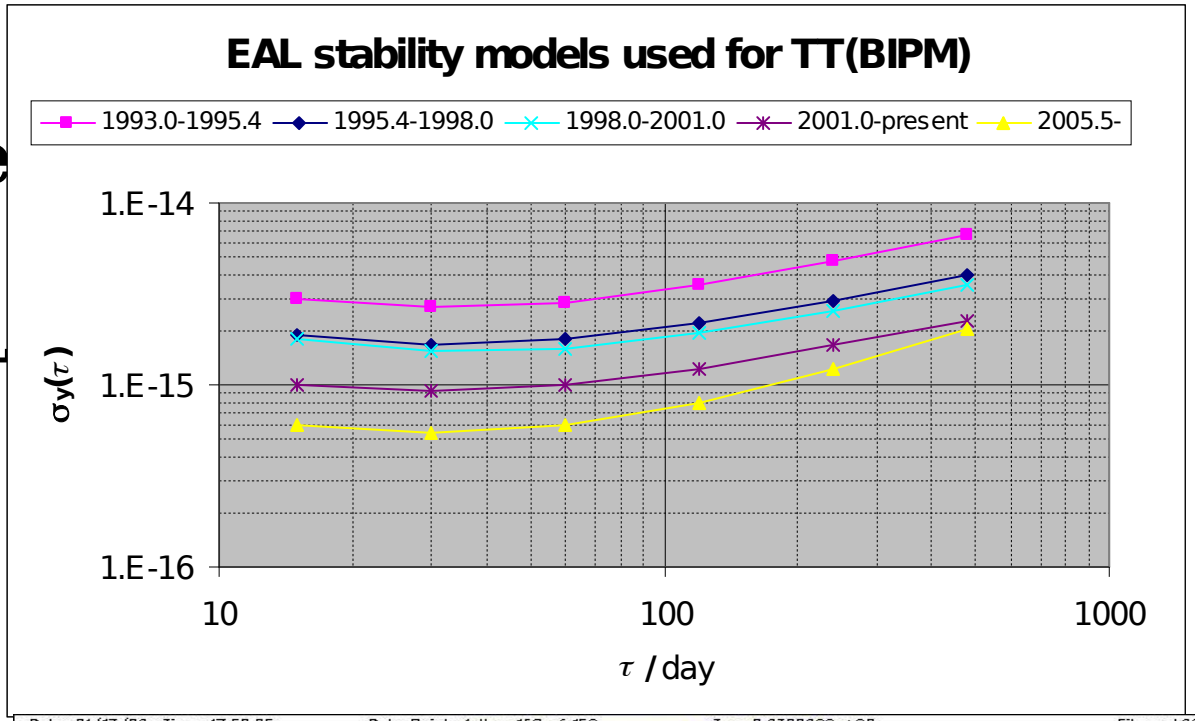
Comparison of EAL to TT(BIPM)

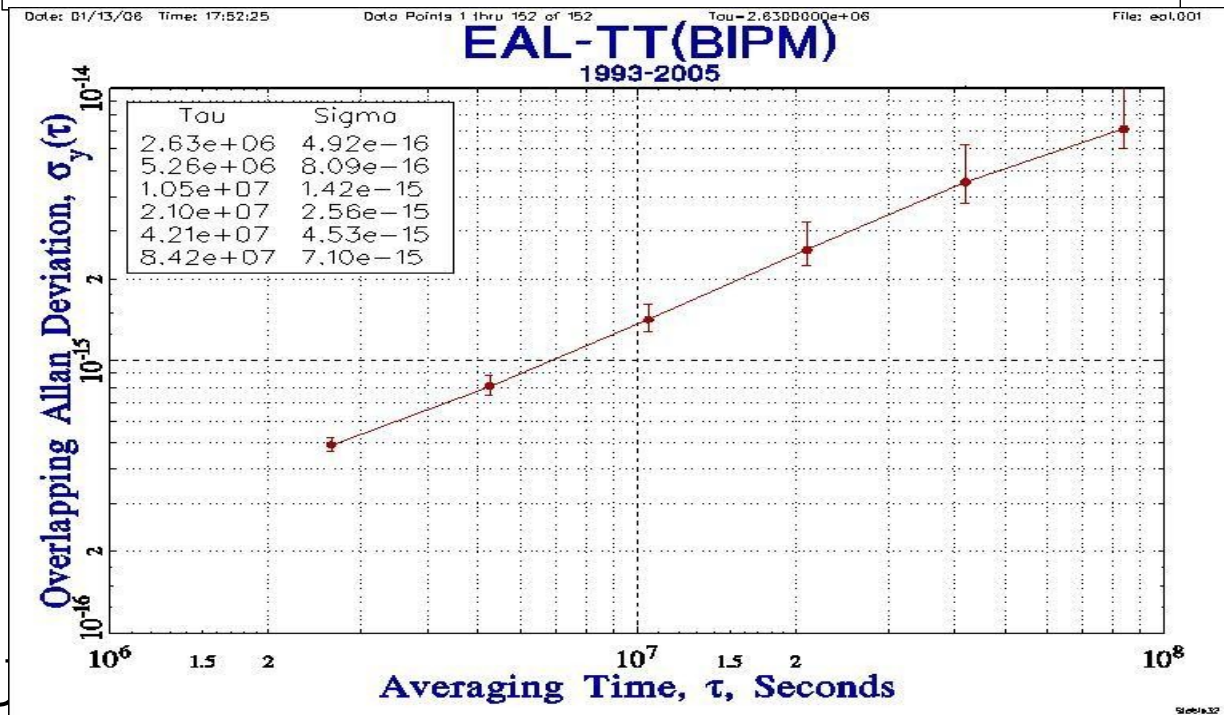
- f(EAL) is compared to TT(BIPM): Some systematic frequency trends persist for many years



Stability of the free atomic time scale EAL

- Improves over time, mostly for 10 d to a few months
- For several years, limited to the 10^{-14} level





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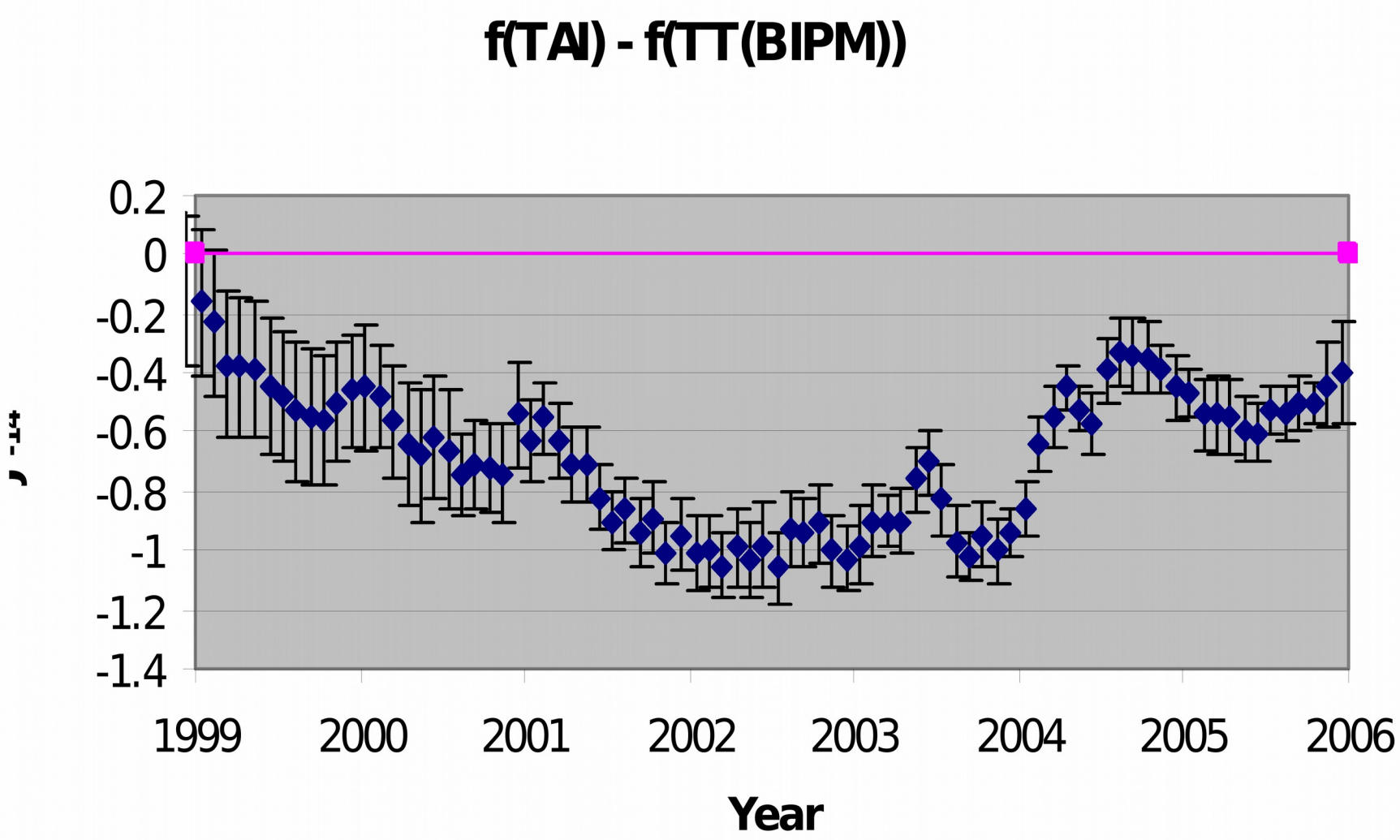
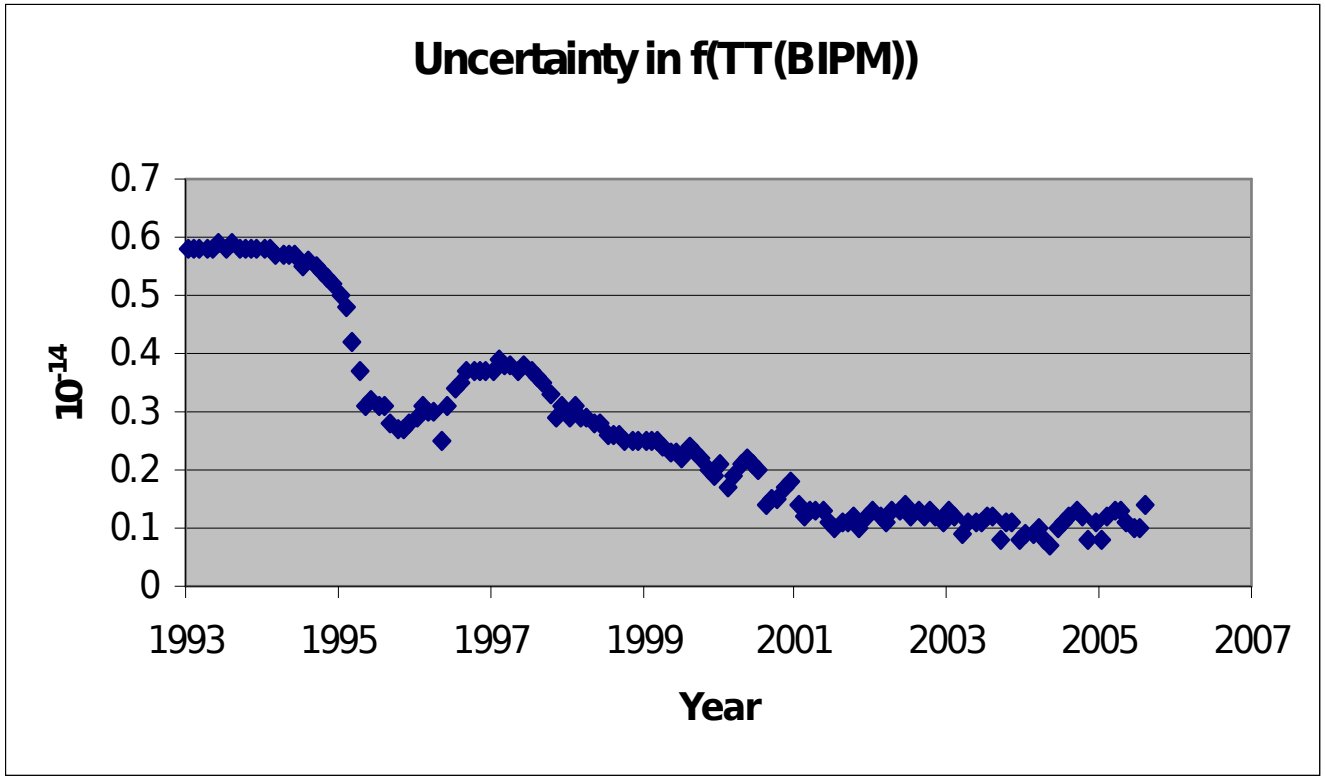
TAI is not as accurate as TT(BIPM). Instabilities of several 10^{-15} over a few years are possible



The latest realization TT(BIPM05)

- Post-processed in early 2006 using all primary frequency standards data until December 2005.
- Frequency accuracy over the period under study: decreases from 6×10^{-15} in 1993 to about 1×10^{-15} since 2001.



Limits to the stability of pulsar time (1995)

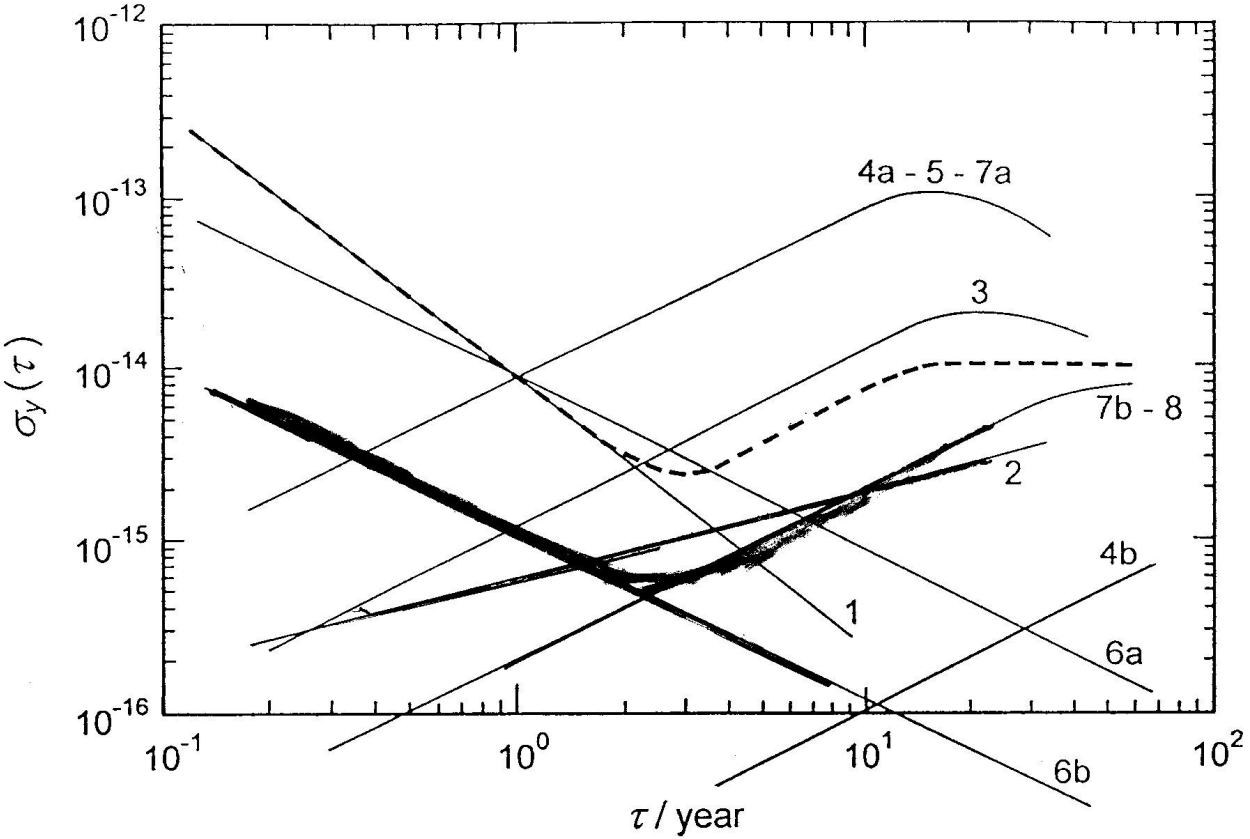
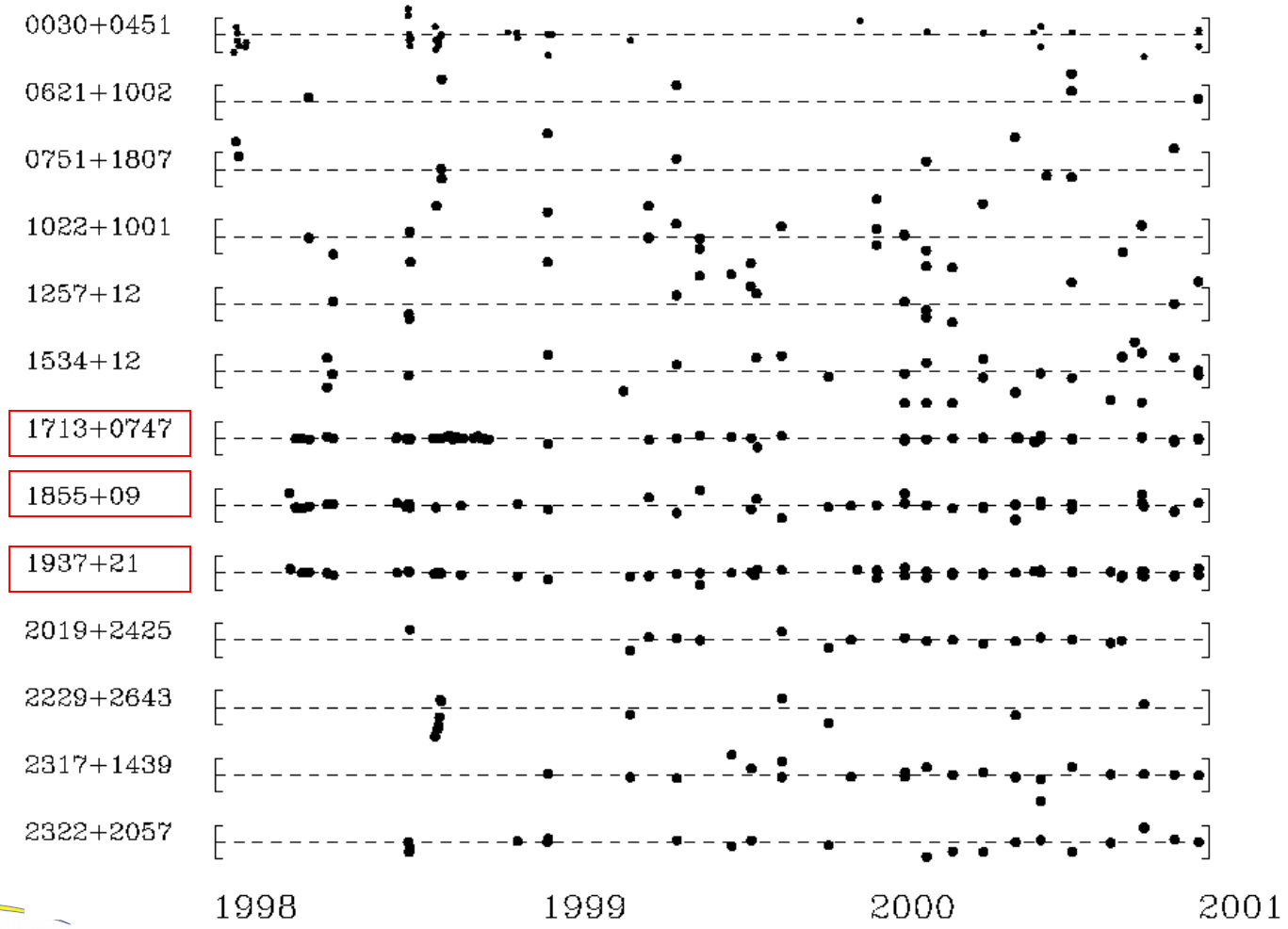


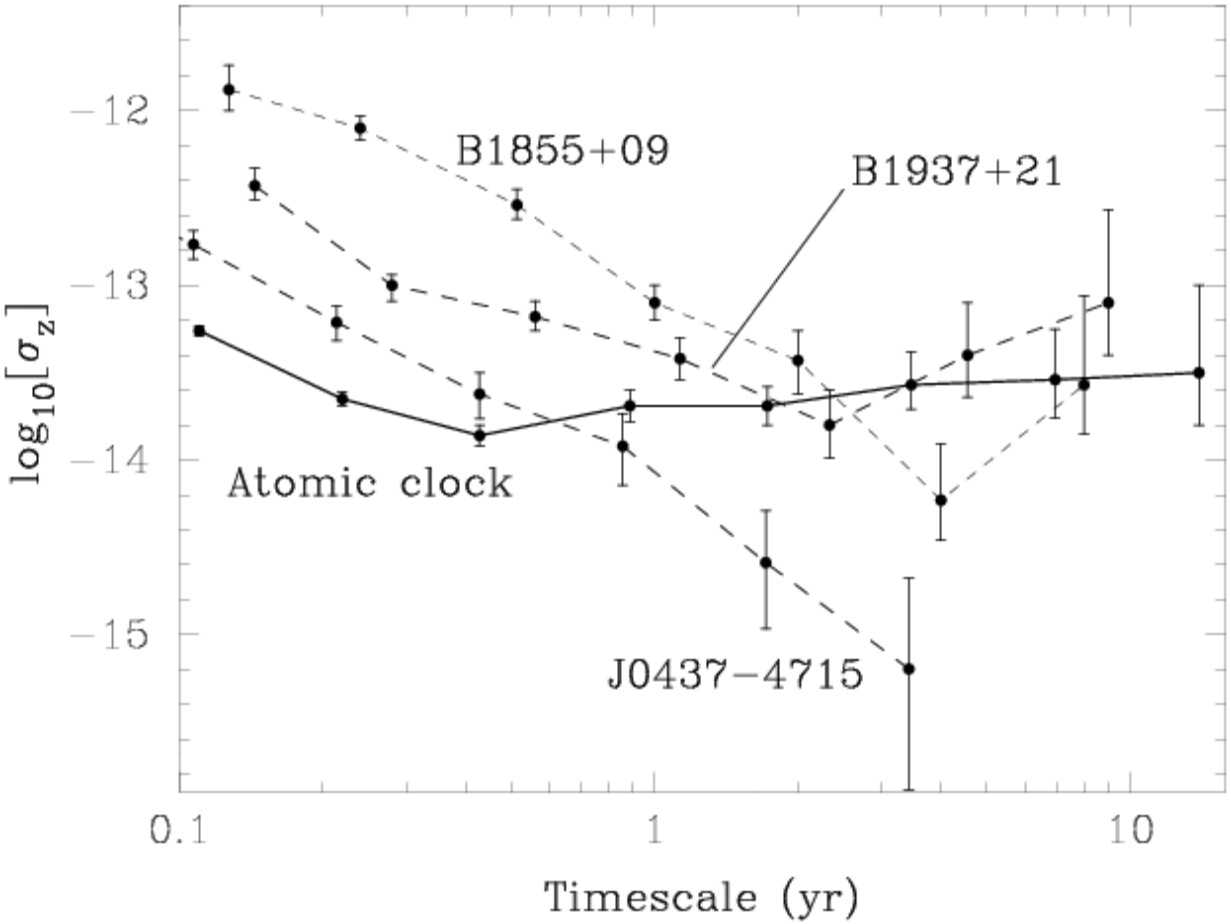
Figure 1. Fractional frequency stability of the effect on pulsar timing of several phenomena: 1 = measurement noise; 2 = geodetic precession; 3 = intrinsic noise; 4 = gravitational jerk (a = maximum, b = typical); 5 = gravitational pull of long period companion; 6 = interstellar medium (a = maximum, b = typical); 7 = gravitational delay of intervening mass (a = maximum, b = typical); 8 = error in solar system barycentre. The dashed curve represents the stability of pulsar time, assuming average conditions for the effects above.

D. R. Lorimer, "Binary and Millisecond Pulsars at the New Millennium", http://relativity.livingreviews.org/Articles/lrr-2001-?/



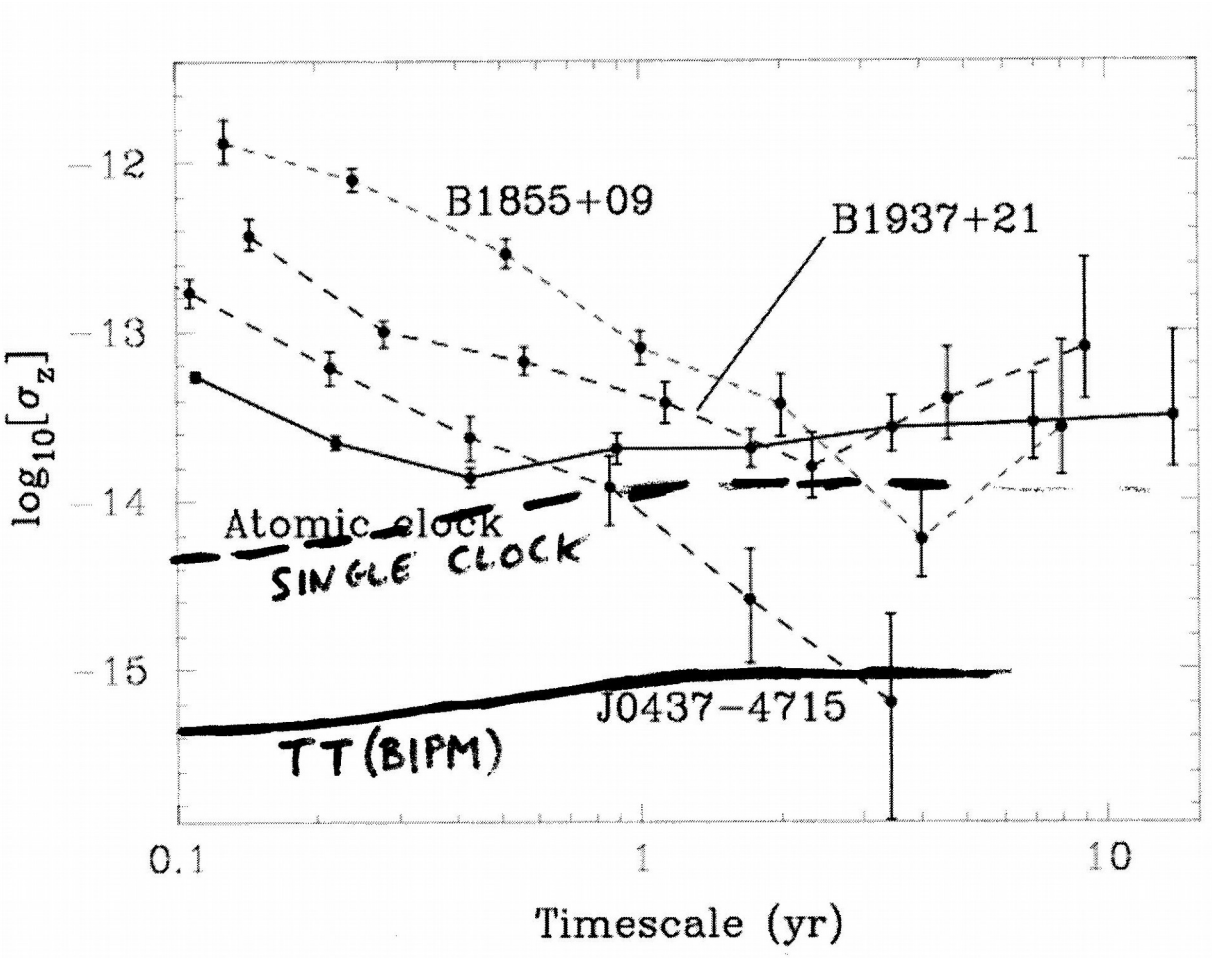
D. R. Lorimer, "Binary and Millisecond Pulsars at the New Millennium", http://relativity.livingreviews.org/Articles/lrr-2005-7/

- 1937+21 and 1855+09 are same old data
- J0437-4715 is from A. Hotan (pers. comm. to DRL). It has very low timing noise (100 ns). Not found published long-term timing analysis.



If we update the performance of atomic time

- A very good pulsar may be as good as one clock above one year
- Atomic time will not be worse than 1×10^{-15} in the future.



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List of “best” ms pulsars (compiled by Jason Hessels)

- Should be ms (of course), bright, narrow pulse, not too much dispersed, not in a cluster, have a low Pdot?
- J0437-4715: P = 5.76ms DM=2.6 pc cm-3 D~140pc
  S400 = 550mJy S1400 = 137mJy Binary
- J1713+0747: P = 4.57ms DM=16.0 pc cm-3 D~1.1kpc
  S400 = 36mJy S1400 = 3mJy Binary
- B1855+09: P = 5.36ms DM=13.3 pc cm-3 D~910pc
  S400 = 31mJy S1400 = 4mJy Binary
- J1909-3744: P = 2.95ms DM=10.4 pc cm-3 D~820pc
  S400 = ? S1400 = ~3mJy Binary
- B1937+21: P = 1.56ms DM=71.0 pc cm-3 D~3.6kpc
  S400 = 240mJy S1400 = 16mJy Isolated

Conclusions (1)

- TT(BIPM), updated yearly, has accuracy and long-term instability at about 1×10^{-15} over the recent years.
- TAI, available every month, is less accurate and stable than TT(BIPM), but not worse than a few 10^{-15} over the recent years.
- Primary frequency standards (PFS) have gained about one order of magnitude in accuracy every 10-12 years, and this expected to continue. We are at 4×10^{-16} .
- The full accuracy of PFS may not be completely represented in TT(BIPM) because of
  - the small number of PFS, and their irregular operation
  - the noise of frequency transfer

Conclusions (2)

- Pulsars long-term stability may reach 10^{-15} and would not supersede atomic time scales.
- Nevertheless they are useful for time scales in
  - being the main users of the very long term stability of atomic time scales
  - providing flywheels to transfer the current accuracy of atomic time to the past, or to the future.
- And of course they are fundamental tools to investigate a variety of physical phenomena.